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"A Race Against the Machine: has the Threat of Technological Unemployment Finally Become True?"

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Table of Contents

Abstract

Nel corso dell'ultimo decennio si è assistito ad incredibili miglioramenti da parte delle nuove tecnologie, che ora assolvono a funzioni estremamente più varie che nel passato. Questo elaborato ripercorre gli effetti provocati dalle innovazioni nelle precedenti Rivoluzioni Industriali, per poi concentrarsi sui profondi cambiamenti portati dal computer, analizzando gli effetti a cui possono condurre nel prossimo futuro. Infine vengono presentate le misure più comunemente supportate dagli studiosi per mitigare i possibili effetti negativi.

Introduction

"We are being afflicted with a new disease of which some readers may not yet have heard the name, but of which they will hear a great deal in the years to come: technological unemployment- i.e. unemployment due to our discovery of means of economising the use of labour outrunning the pace at which we can find new uses for labour."

John Maynard Keynes, Economic possibilities for our grandchildren,1930

Since the dawn of the 19^{th} century, humanity has experienced sporadic waves of technological unemployment's fear. After the first automation brought by the Industrial Revolution, protests burst in response to the workers' displacement provoked by the new machines. However, the technological changes occurred in the First and Second Industrial Revolutions always created more jobs than the ones they replaced, leading nations to improve their population's living conditions and allowing for upward mobility. Given the evident benefits brought by new technologies, technological unemployment disappeared from the economic debates for a rather long time (besides a short resurgence in the Great Depression's period), to emerge again only in the 1950s and early 1960s. (See Mokyr et al.,2015)

In 1964, a self-defined Ad Hoc Committee over the Triple Revolution, which included personalities such as Chemist Nobel Prize Linus Pauling, together with Gunnar Myrdal and Friedrich Hayek, two future Economics Nobel Prizes, sent an open letter to President Johnson. The document warned, above all, about the implications of further technological advances, which would have soon required less human labor, leading to huge unemployment and a strong inequality increase, eventually causing a collapse in the demand for goods and services, due to the little purchasing power detained by the consumers. (Ford,2017)

However, the predictions contained in the letter failed to pass history's test leading the document to be soon forgotten, at least until recent years. The rapid pace at which technology is improving nowadays, indeed, has raised renewed concerns about the possibility of a technological unemployment and thus, over the validity on the virtuous relationship between employment and innovation in the long term. The entering of non-routine, non-production tasks by the latest computers, has led many to doubt if in a near future there will still be place for human work. But, is it really different this time? Are new technologies going to outperform human skills to the point of completely replacing human labor? If so, are we prepared to face such a scenario?

The first chapter analyses the First and Second Industrial Revolutions' innovations and their implications in terms of employment and skills.

The second chapter addresses the computers' development, from the Third Industrial Revolution to the latest technological advances, discussing their implications on employment, skills and, to some extent, inequality.

Finally, the third chapter examines the most commonly prescribed countermeasures pointed by the economists to mitigate the disruption the new technologies will cause, with a particular focus on the education's role.

1. The First and Second Industrial Revolutions

1.1 The Industrial Revolution

1.1.1 The inventions and the protests

Economists refer canonically to the Industrial Revolution as the period starting from approximately 1760 and ending around 1820 and 1840. The beginning is collocated in the second half of the 18th century due to its most famous inventions:

- in 1765 James Watt develops an improved steam engine[1] (which was actually invented already in 1712, but was still highly inefficient and therefore unfit for industrial uses),
- in 1785 Edmund Cartwright patents the power-loom for weaving cloth[2]

[1] https://courses.lumenlearning.com/boundless-worldhistory/chapter/steam-power/

These two major inventions radically transformed Great Britain from an organic economy (i.e. based on materials and energy coming from wood and animals) to a mineral one (based, instead, on iron and fossil fuels). (Mokyr,2004)

This shift was allowed by the widespread use of the steam engine, the GPT (General Purpose Technology) characteristic of the Industrial Revolution: steam power enabled the conversion of heat energy to a mechanical one, leading to its adoption by any industry needing a source of portable power. The steam engine determined the rapid diffusion of mechanical looms and a revolution in terms of sea and land-transportation, thanks to the development of railroads and long-distance steamships. (see Chin et al.,2004)

The drastic changes brought by the new machines, however, led to widespread riots. The mechanical looms' introduction, for instance, led to the birth of the Luddite. The Luddites were textiles workers, whose job was made redundant by the new machines, who starting in 1811 began to smash machines in nocturnal raids and threat masters who adopted the new frames.[3] The reasons beneath these protests can be traced in the structure of the pre-industrial society.

Before the Industrial Revolution, manufacturing was mostly dominated by skilled artisans who performed craft production. Craft work was characterized by a high level of sophistication and skill, thus requiring several years of learning to master the techniques. The long time apprentices needed to train to succeed to their master was not only due the sophisticated techniques, but a result of a complex organization which controlled the different networks of shops: the guilds' system.(Amatori&Colli,2011)

The guilds were established according to the different works' typologies and were aimed to regulate the relative markets. Through quantity and quality regulation of the goods produced in a given city, the guilds avoided prices' fluctuations, protecting the interest of their category. The control was enforced by severe regulations on the number of apprentices a master was allowed to hire in his shop, together with strong disincentives to develop innovations which could undermine the craftsmen's social and economic position. (Amatori&Colli,2011)

This rigid system was aimed to the preservation of the privileges detained by the artisans, making the pre-industrial society a rather infertile plot of land for the seeds of progress. As stated by Frey and Osborne (2013), "…it wasn't the lack of inventive ideas that set the

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[2] https://courses.lumenlearning.com/boundless-worldhistory/chapter/textile-manufacturing/

[3] https://en.wikipedia.org/wiki/Luddite

boundaries for economic development, but rather powerful social and economic interests promoting the technological status quo".

Given the structure of the pre-industrial society, it appears quite understandable why the mechanical looms' appearance triggered protests throughout all the Great Britain. The Luddites were attending the dissolution of the status quo so well preserved until that moment by a machine which deskilled their work, undermining their prosperity. In 1812, The Frame Breaking Act (1812) made destruction of frames punishable by death, posing, together with the troops sent to the critical areas, an end to the turmoil. This eventually allowed for the mechanical looms' diffusion.[4]

Year	Power looms in UK
1813	2,400
1820	14,150
1833	100,000
1850	250,000
1861	400,000

Source: http://www.cottontimes.co.uk/workers/

The adoption of the Industrial Revolution's innovations in Britain led the country to achieve an undisputed international leadership, with the other European powers following its lead. The competitive advantage reached by Great Britain through the break of the status quo eventually weaken the privileges' preservation in favor of the achievement of a greater international competitiveness.

Nevertheless, it would be inaccurate to label all the protests which burst in Great Britain in the 19th century as mere status quo's conservation. In 1830, the miserable economic conditions experienced by agricultural workers (caused by economic policies, the enclosure of the commons, etc.), were exacerbated by the appearance of the threshing machine which led to the outbreak of the Swing Riots.(Mokyr et al.,2015) The rioters followed the Luddites' example and disrupted the new machines, the only physical manifestation of oppression on which they could obtain revenge.

Thus, machine smashing and riots were not a prerogative of a rather small group of skilled artisans who feared to lose their privileges, but also the response implemented by impoverished peasants who saw in the deployment of the threshing machines a worsening of

[4] https://en.wikipedia.org/wiki/Luddite

their condition. The partial automation, (and hence, unemployment) these innovations brought caused a displacement of workers who had to find a new occupation to provide for themselves and their families.

1.1.2 The sector and skill shift

The introduction of power looms and new machines in the textiles industry, powered by the steam engine, revolutionized many aspects of society: given their dimensions, they were unfit to be kept in the households, hence requiring a bigger workplace where workers were gathered altogether, splitting once and for all the workplace from the household.

The gathering of most of the production process in the factory led to many changes in the way people performed work: the pace was now determined by machines and not by the natural ongoing of the sunlight as in the primary sector. Furthermore, factories' conditions were not regulated for a long time, significantly exposing workers to industrial accidents and contagious diseases which spread rather easily due to the enclosed spaces where workers were gathered. Regulation by institutions came only rather late, allowing entrepreneurs to arbitrarily manage every aspect of the workplace until that moment.[5]

The spreading of the mechanical looms led, as we have seen above with the Luddites' emergence, to the replacement of high skilled weavers by unskilled workers. As Frey and Osborne (2013) put it: "[a] deskilling process (work that had previously been performed by artisans was now decomposed into smaller, highly specialized, sequences, requiring less skill but more workers, to perform) occurred as the factory system began to displace the artisan shop, and it picked up pace as production increasingly mechanized with the adoption of steam power. […] The one-man job was turned into a 29-man worker operation, reducing the overall work time by 34%. […] Physical capital provided a relative complement to unskilled labor, while substituting for relatively skilled artisans."

Hence, capital, in the form of investments in the new machines, substituted for relatively high skilled labor, while complementing unskilled one, ultimately leading to a sharp employment rise, since the job previously performed by one man was now split among many more. The labor required by the new factories came mostly from the countryside, leading to a huge sector shift from the agriculture to the industry.

[5] https://courses.lumenlearning.com/boundless-worldhistory/chapter/social-change/

The dimensions of this sector shift can be better understood by Craft's estimations (1985, tab 3.6), reported by Amatori and Colli (2011), which show how the percentage of the British male labor force employed in agriculture in 1760 was approximately 53 percent and the share of income derived from the primary sector was 37.5 percent. Eighty years later, agriculture in Britain employed slightly more than one-quarter of the male workforce, whereas the primary sector only contributed 25 percent of total income.

Given the large demand for unskilled work, the displacement that many workers experienced did not last for long and thus, avoided for the risk of a technological unemployment.

Besides the many unskilled jobs in the factories, the Industrial Revolution's innovations led to the creation of a whole new class of engineers, whose designated task was the new machines' maintenance. On this regard, it seems useful to report the results obtained by Chin et al. (2004) who addressed the effects on wages and employment in the merchant marine registered in the Atlantic provinces of Canada from 1865 to 1912, a period which experienced the substitution of steam for sail.

The scholars found how the steam-powered ships' introduction led to a consistent cut in the wage bill shares of seamen, which passed from 65% on sail-powered ships to less than 20% on steam-powered ships. This occurred due to the replacement of the seamen in favor of higher skilled engineers and unskilled engine room operatives who together accounted for more than 50% of the wage bill share.

Thus, considering the technological change to be exclusively unskilled-biased could be too simplistic: if it is true that machines replaced skilled human labor in many fields, they also created technicians and engineers, high-skilled and paid figure who would eventually assume a fundamental role with the outbreak of the Second Industrial Revolution.

1.1.3 Steam engine and productivity growth

Mechanical looms significantly raised the textiles industries' production levels, leading to enormous labor productivity gains which allowed Great Britain to reach a powerful international position.

These machines, however, were still powered for a long time with water rather than steam. The Industrial Revolution's GPT, indeed, experienced a rather slow diffusion compared to mechanical looms, thus, delaying its impact on productivity.

Year	Steam horsepower
1800	35,000
1830	160,000
1870	1.7 million
1907	9.65 million

Source: Crafts, 2002

According to Greenwood (1999) the lag between the steam engine's invention and its widespread adoption find a reason in two main factors: the speed of diffusion and the speed of learning.

Regarding the first factor, a Watt steam engine cost only £500-800; operating it, though, was incredibly expensive: its consumes reached 7.5 pounds of coal per annum, which meant 3000£ of coal, given the prices of the epoch. Quite naturally, the high cost of steam engine's annual consumption made the technology's adoption prohibitive for many industries, leading only a few entrepreneurs to employ the new energy source. Only later, already around 1850, the quantity of coal was reduced to 2.5 pounds, a decrease which fostered the innovation's diffusion. (Greenwood,1999)

The speed of learning, i.e. the time needed by people to fully understand the many applications allowed by the GPT, played a nonetheless important role. Given the several purposes the steam engine could serve, the time required by entrepreneurs to fully understand its functioning was rather long. People needed to first understand the potential of the emerging technology, and then ideate new machines which exploited the innovative energy source: ships had to be deeply reshaped to embody the steam engine, while locomotives had to be completely invented.

Furthermore, even after understanding the possible applications of steam engine (e.g. in the textiles factories), entrepreneurs needed to proceed to a whole reorganization of their plants, which implied huge investments that not everyone was willing to implement. This, together with the time workers demanded to cope with the changes in the production, necessarily implied a slowdown in productivity.

SOURCES: Harley (1993) and Lindert and Williamson (1983).

Source: Greenwood,1999

The graph shows how productivity slowed down from 1760 to 1800, the period which led to the steam engine improvement and the mechanical loom's invention, reaching significant increases only around 1850, once the major adjustments were completed and the cost to operate the steam engine had consistently declined.

Furthermore, the graph also reports how the wealthiest 10 percent of the population considerably increased the share over the national income they owned thanks to the capital many of them invested in the new means of production. The innovations' advent, and the subsequent factories' appearance, deprived workers of the means of production, that, on the other hand, allowed capital owners to become entrepreneurs, enhancing their wealth.

1.2 The Second Industrial Revolution

1.2.1 The American electrification

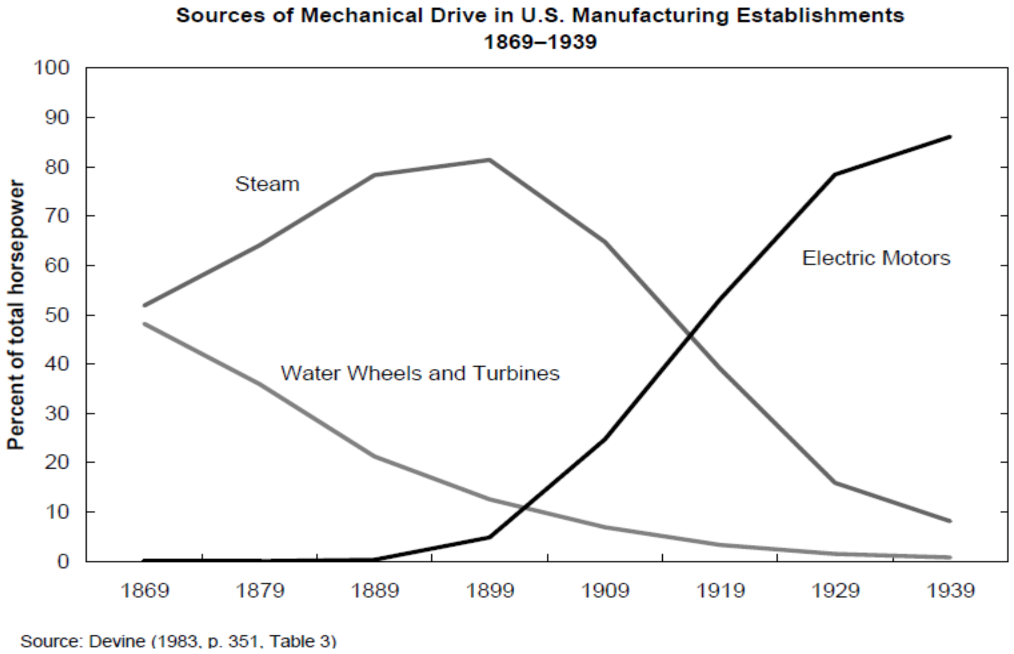
The Second Industrial Revolution goes from approximately 1870 to 1914, right before the outbreak of the WWI.

This period was characterized by many groundbreaking inventions, which led to a drastic change in society's structure and shape. The economic growth's pace in this Industrial Revolution was so extraordinary that "… all other centuries—even the 19th—were standing still". (Brad DeLong cited by Gordon,2000) The country which led the world in this transition was the United States, which reached an unchallenged leadership for most of the 20th century, leading many historians to define it the "American Century". (Goldin&Katz,2008)

Since the inventions were several, the 5 clusters listed by Gordon (2000) may help to reach a better understanding on how society was dramatically reshaped by the Second Industrial Revolution's outbreak:

1. Electricity, the GPT characteristic of the Second Industrial Revolution, dates from the invention of the electric light bulb in 1879 by Thomas A. Edison. Electric motors, once developed, revolutionized manufacturing by decentralizing the source of power and making possible portable tools and machines. Electric motors embodied in consumer appliance, thing that occurred after a longer lag, allowed products such as washing machines, dish washers, ovens, refrigerators, air conditioning and so on.
2. The internal combustion engine, which revolutionized the transportation's sector, made possible personal autos, motor transport and air transport, together with the blooming of many collateral industries.
3. The third group of great inventions includes petroleum, natural gas, and various other process such as chemicals and plastics, which made possible the creation of new and improved materials and products.
4. The fourth cluster consist of the complex of entertainment, communication and information innovations such as the telegraph (1844), the telephone (1876), phonograph (1877), popular photography (1880s and 1890s), radio (1899), and television (1911).
5. Finally, the rapid spread after 1880 of running water, indoor plumbing, and urban sanitation infrastructure led to consistent enhancements in the hygienic conditions and to a subsequent decline in mortality in the four decades prior to WWI.

Electricity, however, represented the key invention for the diffusion of the many goods made possible by the innovations listed above. Manufacturing horsepower in the form of purchased electricity rose from 9 percent in 1909 to 53 percent in 1929, allowing for new products such as automobiles, airplanes, commercial radio, aluminum, synthetic dyes, and rayon; household electric appliances (e.g., refrigerators and washing machines) and office machinery (e.g., calculators, dictating machines, and copying equipment). (Goldin&Katz,1998)



Source: Atkenson and Kehoe,2001

The graph shows how, although electricity was invented already in 1879, its diffusion experienced a sharp rise only from the beginning of the 20th century, to provide half of the total horsepower only around the 1920s, eventually causing productivity growth. The delay experienced by the new technology can be partially explained by the same factors that affected steam engine in the Industrial Revolution: the speed of learning and the speed of diffusion.

Relatively to the speed of learning, electricity was characterized by an greater complexity, which thus, required more skills to be fully understood and exploited. Above all, the need for a significant basis of engineers revealed itself crucial for the correct embodiment of such technologies in the plants. As observed by Goldin and Katz (1998) "the mechanization of the hauling and conveying of materials decreased the relative demand for unskilled labor and increased capital intensity, and the faster and hotter running of machinery powered by electric motors required relatively more machine maintenance personnel." The engineer's figure, a blurry shadow in the Industrial Revolution, played a fundamental role to allow the diffusion of the innovations brought by the Second one.

Together with the higher complexity of the new machines, the graph underlines how, in the year electricity was invented, steam engine had yet to reach its highest diffusion. The overlapping of the two energy sources consequently hampered the diffusion of the second. As David (1990) puts it: "the slow pace of factory electrification […] was attributable to the unprofitability of replacing still serviceable manufacturing plants embodying production technologies adapted to the old regime of mechanical power derived from water and steam."

Steam engine's adoption, indeed, had led to huge investments to embody the technology in the plants, not to mention the vast knowledge built up on its uses by the workers. For an entrepreneur, to shift to a marginal technology the moment he had reached a steady position thanks to the previous one's deep understanding and wide adoption, was unthinkable. This explains why only "the American industries that were enjoying the most rapid expansion in the early twentieth century (tobacco, fabricated metals, transportation equipment, and electrical machinery itself) […] afforded [the] greatest immediate scope for the construction of new, electrified plants" (David,1990)

1.2.2 From production works to non-production ones

The mass production allowed by the widespread electrification and the introduction of continuous processes required increasing firms' layout and capital-output ratio, leading to the establishment of big businesses. The high volumes of goods produced allowed the big manufacturing plants to exploit consistent economies of scale, gaining an important competitive advantage on their small factory competitors. (Amatori&Colli,2011)

However, "if access to these technologies had been available decades earlier, it would have been impossible for these same firms to realize economies of scale and scope in capital-intensive industry" (Amatori&Colli,2011 p.75) Only the wide and dense railway network rapidly built in the US during the 19^{th} century (where in 1860 there were 30,000 miles of railroad tracks, against the 30 miles in 1830[6]), together with an increasing number of steamships, made possible for the vast quantity of new goods to be distributed throughout all the country, meeting an adequate demand.

The mass production allowed by the Second Industrial Revolution's inventions, together with the adoption of Taylor's "scientific organization" of work by many industries (through the deployment of assembly lines in which a great number of unskilled workers were assigned a simple task to perform) led to a sharp rise in the employment's share and wages' level, which compensated the laborers for the dehumanization brought by the new division of labor. (Amatori&Colli,2011)

[6] Greenwood,1999

Nevertheless, the automobile's industry, probably the most representative good of the Second Industrial Revolution, brings an evidence of the evolution undertaken by most of the big manufacturing plants. At first cars were assembled in large artisanal shops by high-skilled craftsmen; as the process was better understood the firms employed unskilled workers through the Ford's famous assembly line. Much later, an increasingly robotized assembly line made unskilled labor redundant, favoring the employment of more skilled machine crewmen. (Goldin&Katz,1998)

This development path was followed by the vast majority of the manufacturing plants, which gradually required less production workers thanks to the switch to electricity and the introduction of continuous processes, whereas the demand for white-collar and technical non production ones (engineers and chemists) rapidly increased. (Goldin&Katz,1998)

Thus, the Second Industrial Revolution led the percentage of blue collar workers to first rise, due to the widespread adoption of the assembly line, and then shrink as more sophisticated machines replaced the routine tasks previously performed by unskilled labor. This caused a huge shift of workers from production works to non-production ones, which eventually employed the majority of the population.

The raise in the complexity of big businesses' organizational structures led to the emergence of a whole new class of clerks, assistants and employees, which formed the so-called white-collar workers. Non-production works such as white-collar ones (e.g. clerks, assistants and employees) but also workers employed in the retail or accommodation industries, required, nonetheless, a higher level of skills than the mere performance of simple tasks on the manufacturing plants' assembly lines.

1.2.3 Which role for education?

Besides the availability of a wide and dynamic market, connected by a dense network of railways and steamships' routes which fostered the establishment of mass production, the US were decades ahead of every other developed nation on what was probably the most crucial factor to take the best advantage of the Second Industrial Revolution's radical changes: education.

As deeply analyzed by Claudia Goldin and Lawrence F. Katz in "The race between education and technology" (2008), the feature that more than any other allowed the US to jump ahead and lead the other developed nations in the 20^{th} century was its mass education. Already in

1900, the country had begun to educate its masses regardless of their personal station and residence: even the most rural Americans had the possibility of sending their children to public secondary schools, thanks to the funds invested by the local institutions and, later, by the state.

The public provision and funding made possible even for the poorest families to provide their children with educational attainment, which allowed for a renewed upward social mobility. Furthermore, the openness to every child, regardless of its school performance or gender, allowed many students to attend high-school and find the occupation which competed them the most afterwards, whereas in Europe only the brightest students had the possibility to study beyond the primary school.

In point of fact, what is now seen as a fundamental right by all the developed countries, i.e. free access to education, was, at the time, defined “wasteful” by many European observers, whose countries implemented a highly meritocratic educational system.

The creation of a large educated working class allowed the massive non-production workers’ demand burst with the Second Industrial Revolution’s outbreak to find an adequate workforce, whose education accounted for almost 15 percent of the labor productivity change occurred across the 20th century (see Goldin&Katz,2008).

Labor productivity consequently translated into higher wages, which allowed workers to accumulate wealth rather rapidly. The mass education provided by the US not only allowed businesses to find an adequate supply of labor for the growing complexity of their organizational structure, but balanced the workers’ remuneration, given their abundant supply. (Goldin&Katz,2008)

Thanks to the large supply of labor, the wealth spread to a larger share of population, instead of concentrating only in the hands of the few ones in possess of a higher education, hence leading to a significant decrease in the income inequality, which allowed for a rising upward social mobility. This, at least, until the 1970s and the outbreak of the Third Industrial Revolution, when the gap narrowing stopped to begin to widen again.

2. The Third and Fourth Industrial Revolutions

2.1 The Third Industrial Revolution

2.1.1 The innovations

With the Second Industrial Revolution's advent, innovations were no more driven by little knowledge and intuition, as for the mechanical looms and steam engine, but by a steady epistemic knowledge's basis, which required intense research and great expenses. (Mokyr,2004)

This led to the establishment of "national systems of innovation", which involved governments, universities and businesses to address coordinated efforts in R&D.

The WWII's outbreak removed most of the budget constraints this cooperation had formerly experienced: in the US alone, federal expenditures for research rose from 80 million dollars to more than 1.3 billion dollars between 1940 and 1945. (Amatori&Colli,2011)

This dramatic expenditure of money, which continued in the aftermath of the WWII with the Cold War, finally led to the outbreak of a Third Industrial Revolution.

This new wave of innovations involved at least three broad clusters of businesses[7]:

1. The first cluster was in communications, which Internet and modern communication system impressively changed, leading to the creation of massive communication networks.
2. The second area affected was transportation: bigger and faster aircrafts were built out of more sophisticated or new materials and powered by jet engines.
3. The last area in which Third Industrial Revolution innovations clustered was physical materials: research programs using atomic energy for peaceful purposes were initiated immediately following the war.

A key factor in all sectors of the Third Industrial Revolution was, however, the availability of a GPT: as steam engine and electricity before it, the semiconductor (1947)—and its successors, the microchip and microprocessor—allowed the development of the clusters mentioned above, given its fundamentality to telecommunications, household appliances and transportation industries.

Above all, the creation of microchips, microprocessors, and memory capacities able to process growing amounts of information quickly and at a rapidly decreasing cost per unit, was essential to the development of personal computers, which experienced a growing diffusion from the early 1970s onwards. (Amatori&Colli,2011)

[7] Amatori and Colli,2011

2.1.2 ICTs and productivity growth

When the era of computers began in the 1950s, they were primarily used in academic and industrial research to perform calculations impossible to do manually. Later in the 1960s they became file-keeping devices used by businesses to sort, store and process large volumes of data; to eventually evolve, with the advent of remote accessing and networking in the 1970s, into communication devices. (Greenwood,1999)

In 1987, Robert Solow, who won the Economics Nobel Prize the same year, published an article on The New York Times observing how “You can see the computer age everywhere, but in the productivity statistics”[8].

This statement opened a debate among the economists over the contribution to productivity, and thus, economic growth, of the new technologies. In 1987, indeed, ICTs had already made great steps forward in their development and brought an whole new set of possibilities. The productivity, however, lagged behind.

The literature which flourished after Solow’s article has found many different reasons for the “productivity slowdown”.

Many scholars (Greenwood,1999; Crafts,2000; David,1990) supported a “transition economy” position which focused on the delay experienced by the GPTs in the former Industrial Revolution.

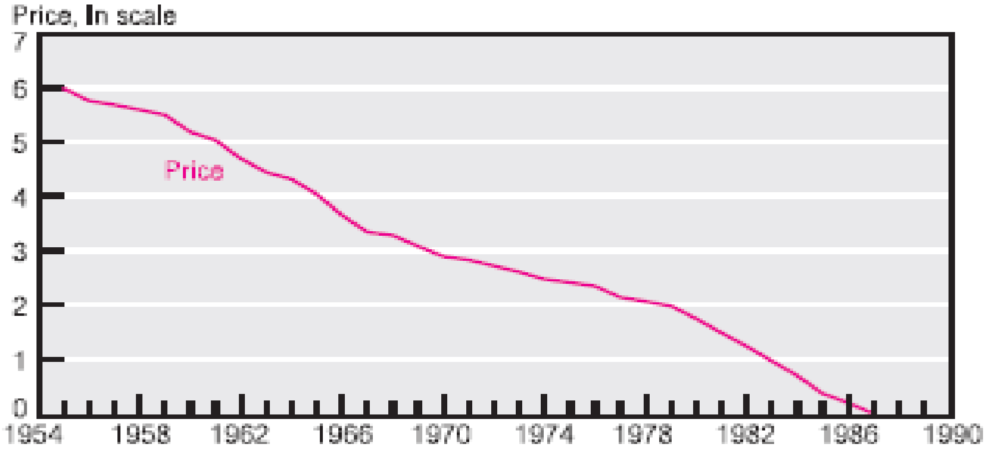
The scholars belonging to this branch of the “productivity slowdown” literature argued how innovations have always experienced a lag between their inventions and the effects on productivity growth, which were significantly hindered by the speed of diffusion and the speed of learning.

However, if steam engine’s and electricity’s costs lowered after a rather long time, computers did not follow the same path. The graph reported beneath shows how, since its invention, computer’s price experienced an average decline rate of 19% annually, whereas steam engine’s operating cost consistently decreased only after almost a century from its invention. (Greenwood,1999)

[8] The New York Times, 12 July 1987

FIGURE 2

Price of New Computers



SOURCE: Yorukoglu (1998).

Source: Greenwood,1999

Moreover, computers did not represent a new energy source, thus, they did not suffer from the slow adoption that affected electricity due to the high embodiment of steam engine within the manufacturing plants. Nevertheless, according to Paillard (2000), the implementation of a new technology occurs gradually, hence implying heterogeneity in the equipment (e.g. the contemporary use of the old and the new one) for a certain period. The simulation model developed in his study shows how “the immediate consequence of the coefficient of heterogeneity is to reduce the productivity of the firms as long as the latter use more than one generation of equipment”. (Paillard,2000)

Even so, the speed of learning probably played a greater role in hampering computer’s diffusion. Given its fast development and continuous change of purpose, learning how to take the best advantage of the new technology’s emergence was certainly challenging, not to mention that enterprises may have been more reluctant to deploy a technology which might have been already obsolete in a few years.

Another trend emerged after Solow’s paradox focused on how the new technologies regarded a field, i.e. information, which the canonical economics methods and means could not measure properly, leading to a systematic mismeasurement of outputs and inputs. (Brynjolfsson,1992)

ICTs’ advantages, which are mostly increased quality, variety, customer service, speed and responsiveness, are among the aspects of output measurement that are poorly accounted for in productivity statistics. For instance, according to Brynjolfsson (1992), the convenience brought by twenty-four hour ATMs is an unmeasured quality improvement on the outputs side, whereas quality of work life improvement thanks to computer usage is among unmeasured improvements on the input side.

Since information is intangible, increases in the implicit information content of products and services are likely to be under-reported compared to increases in materials content. This would explain why most of the productivity slowdown has been observed in the service sector, in which the product itself is intangible and therefore difficult to gauge. (Brynjolfsson,1992)

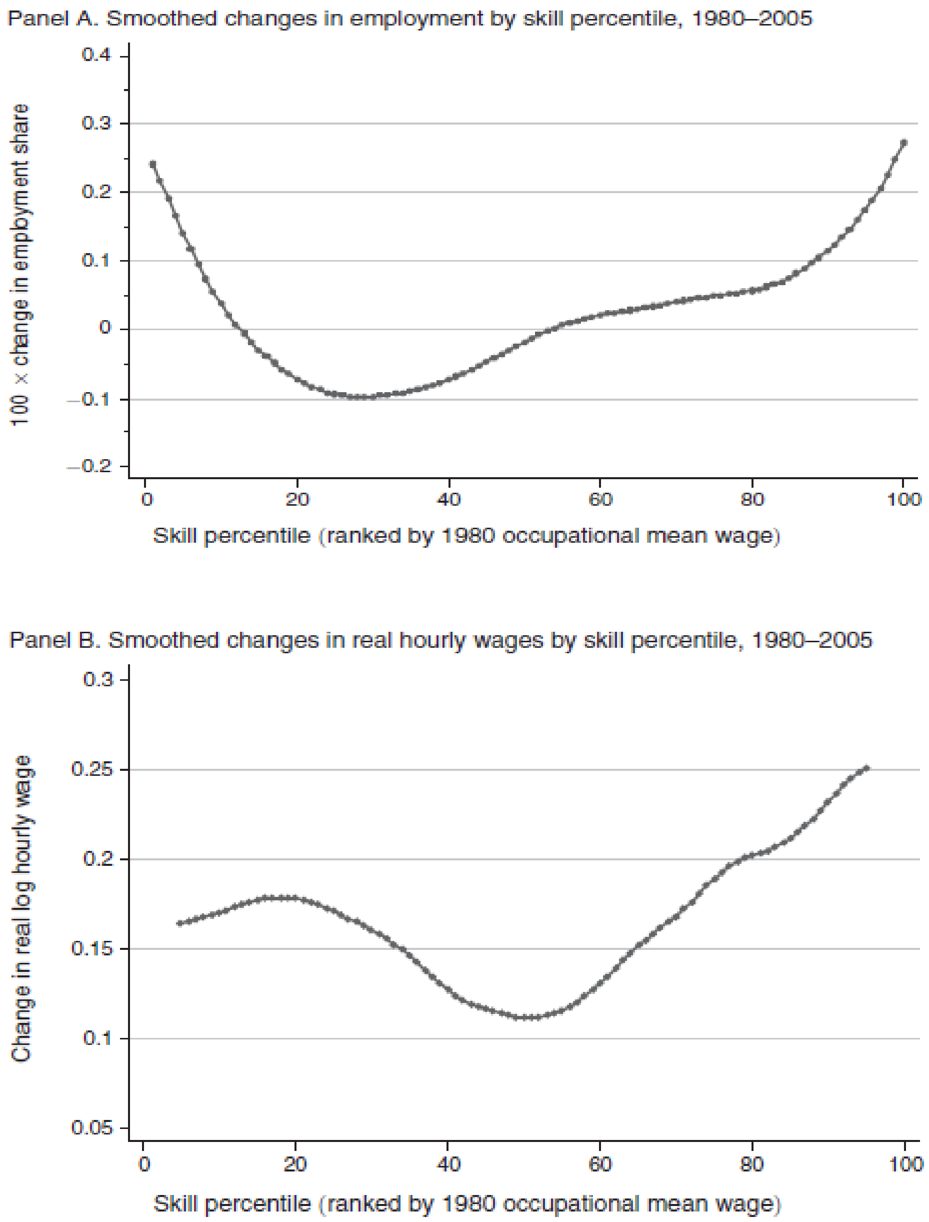
Thus, the dramatic changes ICTs have brought in our lives and in the society as a whole could not be represented by the standard means used to measure economic growth and productivity in the past. (Brynjolfsson,1992)

The two different explanations of the “productivity slowdown” here discussed do not necessarily collide, probably providing a more complete understanding of the Solow’s paradox only when combined together.

2.1.3 A skill-biased technical change

The advent of the Third Industrial Revolution is argued to be, by the vast majority of the economists, among the causes of a huge polarization both in employment and wages.

A paper from Autor and Dorn (2013) focus on the evident US wages and employment polarization occurred in the final quarter of the twentieth century, when the Third Industrial Revolution was experiencing its faster development.



Source: Autor and Dorn,2013

The two graphs reported above show how, between 1980 and 2005, both employment shares and real hourly wages (i.e. wages adjusted for inflation) experienced great gains in the upper tail, modest ones in the lower tail and significantly smaller gains around the median.

The lower tail increases in wages and employment share are caused, according to the scholars, by rising employment and wages in service occupations, i.e. food service workers, hairdressers, beauticians and recreation occupations. As we have already discussed in the previous chapter, if the Second Industrial Revolution first led many firms to employ an increasing number of production workers, the creation of more sophisticated machines allowed for their substitution, leading many low skilled workers to shift to the services, which experienced a rapid growth in the 1980s.

In Autor and Dorn’s opinion, the sharp rise experienced by service occupations accounts for a substantial share of aggregate polarization and growth of the lower tail of the US employment and earnings distribution in the period observed. Looking at the change in share of aggregate employment dividing the lower tail by service occupations and non-service ones leaves little doubt: while between 1970 and 1980 both occupations’ employment share fell, from 1980 onwards only service’s ones experienced an increase, with the non-service occupations falling behind.

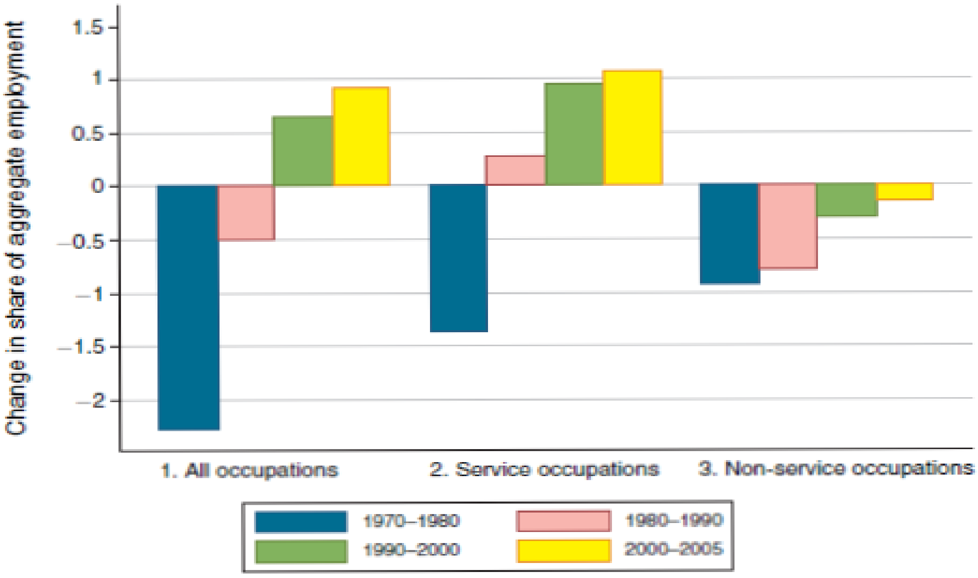
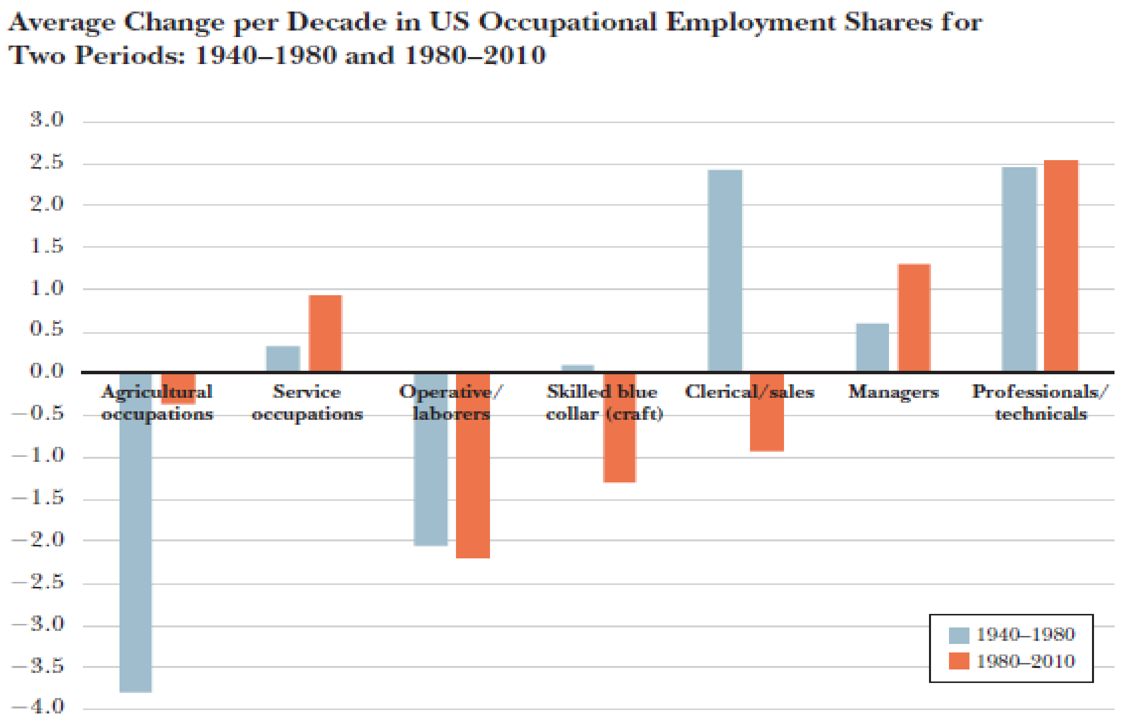


FIGURE 3. CHANGE IN AGGREGATE EMPLOYMENT SHARE BY DECADE 1970 THROUGH 2005 IN OCCUPATIONS COMPRISING THE LOWEST SKILL QUINTILE OF EMPLOYMENT IN 1980

Source: Autor and Dorn,2013

The following graph brings further evidence on how production works, such as agricultural occupations, skilled blue collar and laborers experienced a constant decline in US occupational employment shares since 1940.

Regarding the first period observed, the decline can be ascribed to the already mentioned electrification occurred within the manufacturing plants, which allowed many stages of the production processes to be automated, whereas the new organizational complexity led to an increasing demand for white-collar non production workers. (Goldin&Katz,1998)



Source: Autor,2014

As historical evidence supports, technology has always had two different effects on labor: complementarity and substitution. The former benefits a determined category of workers, while the latter leads to the replacement of another one.

The Industrial Revolution's inventions primarily led to a "deskilling process" which complemented unskilled workers, while substituting for the high skilled ones. The Second Industrial Revolution's outbreak, on the other hand, gave birth to the big businesses and mass production, complementing skilled blue collar and white-collar workers, while substituting the lower skilled ones. Thus, the latter shifted to the services (e.g. cafés, accommodations, recreational businesses) where the middle class generated by the Second Industrial Revolution spent its earnings.

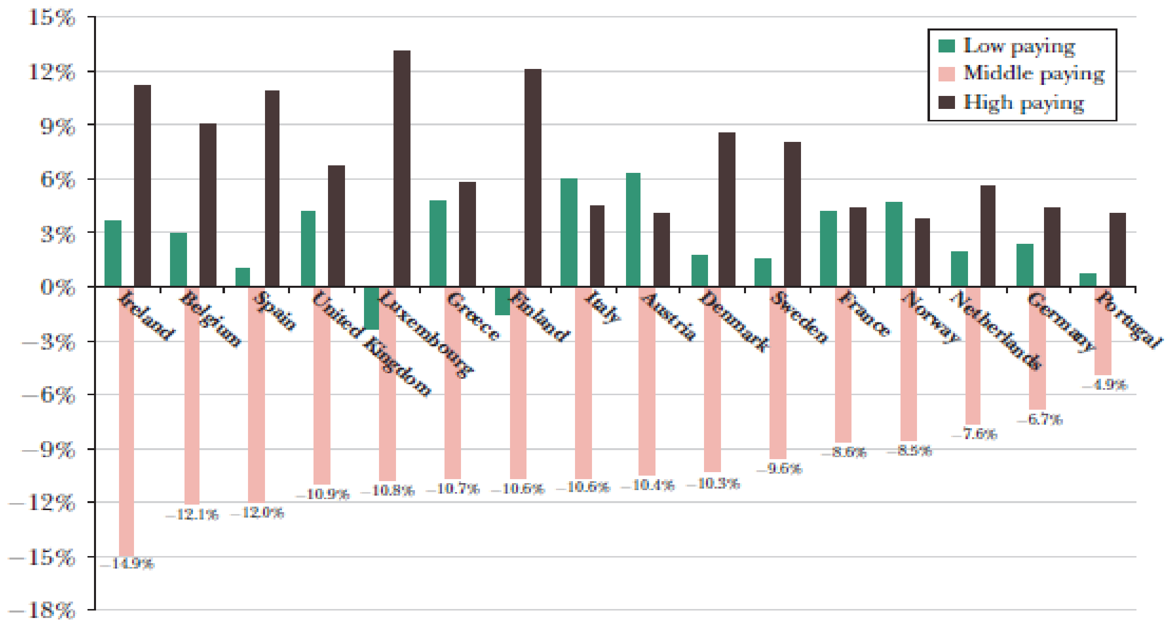
However, the advent of the computer with the Third Industrial Revolution substituted for routine-based jobs, i.e. mostly low skilled production workers and middle skilled ones (bookkeepers, clerical workers), while complementing high-skilled ones. (see again Autor,2013)

This exacerbated the sector shift of the lower tail of the distribution from manufacturing to the service sector, whereas middle skill workers who performed routine jobs were negatively affected, lacking the shift possibilities of the low-skilled ones. Since they could not shift towards the high-skill occupations due to the higher education required, the disruption brought by technology forced many from the middle class to a downward occupational mobility, i.e. towards low skill jobs in the services. This guaranteed the high-skilled workers to experience the highest wage and employment share growth, leading to the definition of a “skill-biased technology”, which favors the highest educated part of the population.

It is important to underline how this U-shaped employment and wage curve, with the subsequent hollowing-out of the middle class, was not experienced only in the US, but was a process experienced by all the most advanced economies.

The following chart shows, indeed, how all the most developed European nations experienced a sharp decline in their middle paying employment share. By contrast, as it happened for the US, low-wage experienced a modest growth, whereas high-wage underwent a sharp rise.

Change in Occupational Employment Shares in Low, Middle, and High-Wage Occupations in 16 EU Countries, 1993–2010

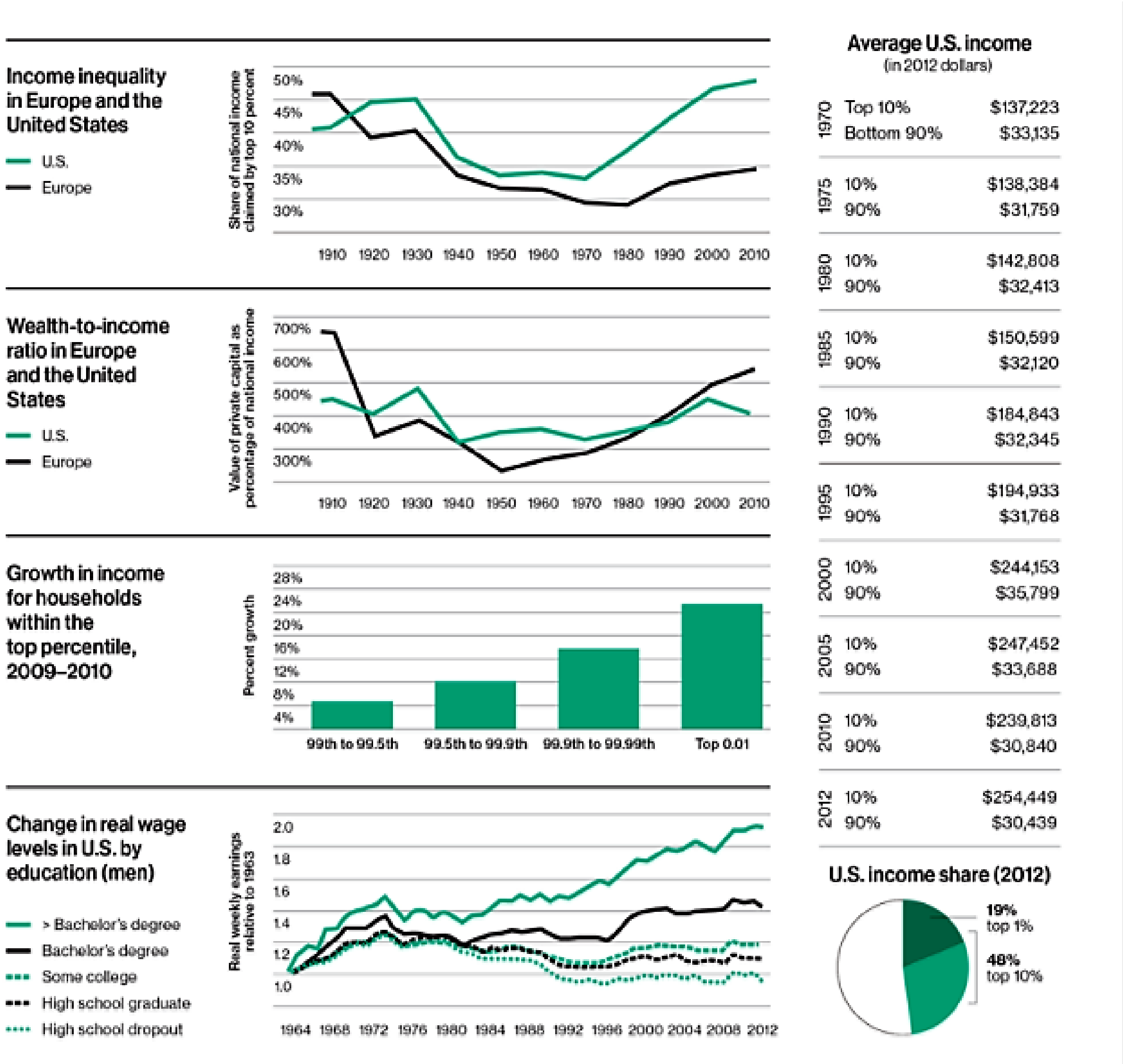


Source: Goos, Manning, and Salomons (2014, table 2), reported by Autor,2014.

2.1.4 An increasing inequality

If the 20th century was mostly characterized by a narrowing of the income inequality in the vast majority of the developed nations, its last quarter showed a completely different trend.
As showed by the graphs and statistics reported by David Rotman in his article for the MIT Technology Review, the income inequality in Europe and the US has experienced a sharp rise since the 1970s, with the gap between the average income perceived by the bottom 90% and

the top 10% widening to the point of reaching $224,010 in 2012, when in 1970 it did not go beyond $104,088.



Source: Rotman, David, October 21, 2014, "Technology and Inequality", MIT Technology Review.

The increasing inequality experienced by the most developed nations is deeply linked to the skill-biased technical change occurred from the 1970s onwards. The change in real wage levels in US by education captures how the advent and diffusion of the computer advantaged higher educated workers, accordingly to the data discussed before.

Erik Brynjolfsson and Andrew McAfee (2011) argue how the most important changes allowed by the ICTs occurred in work organization: the firms which proceeded to a whole reorganization around the ICTs captured the most of the new technologies' advantages, requiring, in turn, higher skilled workforce. This, according to the scholars, explains the sharp rise experienced by high education workers who were able to learn how to correctly use the innovations faster than lower-educated people.

Together with the sharp wages' rise experienced by the higher-skilled workforce, new technologies led to an unprecedented importance of capital relatively to labor. On this regard Brynjolfsson and McAfee (2011) state how "if the technology decreases the relative importance of human labor in a particular production process, the owners of capital equipment will be able to capture a bigger share of income from the goods and services produced". Indeed, data shows that "corporate profits as a share of GDP are at 50-years highs […] [whereas] compensation to labor in all forms, including wages and benefits, is at a 50-year low".

Hence, examples such as the one from Instagram, which in 2012 had 30m customers employing no more than 13 people, represent only a piece of a wider scenario in which capital's importance reached new peaks relatively to labor.[9]

2.2 The beginning of a Fourth Industrial Revolution?

In 1965, Gordon Moore, Intel cofounder, was preparing a speech about the growth trends in computer memory. Graphing the data, he realized the existence of a striking trend: each new chip contained roughly twice as much capacity as its predecessor and was released within 24 months of the previous one. If that trend continued, computing power would have risen exponentially and incredibly fast.[10]

According to Moore's predictions, following this trend, the number of transistors in an integrated circuit would have doubled every two years. This proved to be the case, leading to the birth of Moore's law.

The exponential pace undertaken by new technologies is effectively explained by Ray Kurzweil in "The Age of Spiritual Machines" (2000)[11] through an ancient story in which the inventor of the game of chess brought his invention in front of the country's ruler. The latter was so delighted by the man's invention that he allowed him to choose his reward. Thus, the

[9] ANON., January, 18, 2014. Coming to an office near you, The Economist

[10] ANON., August 23, 2011. Computer History 101: The Development Of The PC

[11] Quoted by Brynjolfsson and McAfee (2011)

man chose for a quantity of rice which should be determined placing one grain of rice on the first square of the chessboard and then doubling the quantity for every following square.

Kurzweil notes how the rice accumulated in the first half of the chessboard is not exceptional, whereas it grows to tremendous amounts advancing on the second half. His point is to show how constant doubling, and therefore exponential growth, is initially unremarkable, looking similar to a standard linear one. Nevertheless, as we move in the second half of the chessboard it accelerates far past linear growth.

This leads to what is probably the most important question regarding technology nowadays: where are we in the history of business use of computer? Are we already in the second half of the chessboard? If so, are we prepared to cope with an exponential growth in technological change's pace?

The ghost of technological unemployment has come back and many scholars now support the belief that this time the outcome may be different.

2.2.1 The tasks in which computers have already bested humans

The exponential pace computers are experiencing is supported by the many progresses they made since their invention: being born as simple calculation means, they rapidly incorporated data storage functions to eventually become communication technologies with the internet advent.

After the transition from ITs to ICTs in the 1980s, the new direction followed by computer research was primarily aimed to the reverse engineering of human skills.

In 1997, Deep Blue, a computer developed by IBM, won the World Chess Champion Garry Kasparov in a chess match, leading to the first game to be won by a chess-playing computer under normal chess tournament conditions.[12]

After this win, IBM Research continued in its efforts to lead computers to the achievement of more complex tasks: many efforts were made for machines to pass the Turing Test, by the name of its creator Alan Turing. The test consists in testing a machine's ability to exhibit

[12] https://en.wikipedia.org/wiki/Deep_Blue_versus_Garry_Kasparov#1997_rematch

intelligent behavior indistinguishable from that of a human; task eventually accomplished in 2014.[13]

By the same token, in 2011 Watson, a pattern-recognizing supercomputer developed by IBM, bested the best human competitors in Jeopardy!, a popular American general-knowledge quiz show.[14] The computer used algorithms which allowed it to recognize patterns and regularities in data, a process much more sophisticated than the simple brute force implemented by Deep Blue to win Kasparov.

One of the most fundamental economics papers on computers' skills is "The skill content of recent technological change: an empirical exploration" by Autor et al. (2003) which analyses the tasks are affected by computers' development. The scholars develop a two-by-two matrix in which tasks are divided by both manual/cognitive and routine/non-routine ones.

PREDICTIONS OF TASK MODEL FOR THE IMPACT OF COMPUTERIZATION ON FOUR CATEGORIES OF WORKPLACE TASKS

	Routine tasks	Nonroutine tasks
	Analytic and interactive tasks	
Examples	• Record-keeping • Calculation • Repetitive customer service (e.g., bank teller)	• Forming/testing hypotheses • Medical diagnosis • Legal writing • Persuading/selling • Managing others
Computer impact	• Substantial substitution	• Strong complementarities
	Manual tasks	
Examples	• Picking or sorting • Repetitive assembly	• Janitorial services • Truck driving
Computer impact	• Substantial substitution	• Limited opportunities for substitution or complementarity

Source: Autor et al.,2003

A routine task is defined by the possibility for a machine to accomplish it following explicit programmed rules. Since "these tasks require methodical repetition of an unwavering procedure, they can be exhaustively specified with programmed instructions and performed by machines" (Autor et al.,2003). Calculation, record-keeping and repetitive assembly, as shown in the matrix, belong to this group.

However, many widespread manual and cognitive tasks do not rely on explicit procedures, and therefore are not completely understood by the agents who perform them. This was first

[13] ANON., June, 9, 2014. Computer AI passes Turing test in "world first", BBC.
[14] ANON., January, 18, 2014. The Future of Jobs: the Onrushing Wave, The Economist.

pointed out by Polanyi, who stated how "we know more than we can tell": "The skill of a driver cannot be replaced through schooling in the theory of the motorcar; the knowledge I have of my body differs altogether from the knowledge of its physiology; and the rules of rhyming and prosody do not tell me what a poem told me, without any knowledge of its rules" (Polanyi 1966, p.20 cited by Autor,2003)

Since computers follow procedures meticulously laid out by programmers, they do nothing but implementing instructions previously encoded by humans. This consequently means that, for them to perform a task, a programmer must first fully understand the sequence of steps required to perform that task and then write a program which makes the machine follow the steps, finally accomplishing the task.

However, the moment a task requires a set of knowledge which is defined as tacit, i.e. not explicitly understood, programmers cannot encode the sequence of instructions into the computer. "When we break an egg over the edge of a mixing bowl, […] write a persuasive paragraph, or develop a hypothesis to explain a poorly understood phenomenon, we are engaging in tasks that we only tacitly understand how to perform" (Autor,2014)

Tasks demanding flexibility, judgment and common sense have proved to be the most difficult to automate, due to the tacit basis they rely on.

Autor et al. (2003) argue, indeed, how computers had and will continue to have a huge substitution impact on routine tasks both on manual and cognitive tasks; whereas non-routine manual tasks exhibit only little opportunities for substitution and non-routine cognitive ones show, instead, strong complementarities.

Non routine manual tasks are characterized by a low skill level, which, nevertheless, require situational adaptability, fine motor coordination, physical dexterity, visual and language recognition and in-person interactions. These basic human skills are, indeed, necessary to workers such as janitors and cleaners, home health aides, construction laborers, security personnel and motor vehicle operators, food preparation and serving. (see Autor,2015b)

On the other hand, cognitive tasks are characteristic of high skill professions which require, besides the already mentioned visual and language recognition and in-person interaction, problem-solving, adaptability and persuasiveness (e.g. managers, researchers, engineers, lawyers and doctors).

The difficulties encountered by computers in perception and mobility go under the name of Moravec's paradox, who indeed writes how "it is comparatively easy to make computers exhibit adult level performance on intelligence tests or playing checkers, and difficult or impossible to give them the skills of a one-year-old when it comes to perception and mobility."[15]

2.2.2 The economic implications

The success of computers in performing routine-based tasks consistently depressed the low skill production workers' employment share and wages, leading to the U-shaped employment share curve earlier discussed.

The diffusion of industrial robots, the most recent developments of the first routine-tasks performing computers, left and will continue to leave many persons without a job.

The International Federation of Robotics (IFR) defines an industrial robot as "an automatically controlled, reprogrammable and multipurpose machine".[16]

In a recent paper, Acemoglu and Restrepo (2017) address industrial robots' effect on US labor market using an "exposure to robots" measure. The results show how "in the most exposed areas, between 1990 and 2007, both employment and wages decline in a robust and significant manner compared to less exposed areas." As a proof of Autor et al.'s (2003) analysis, the effects documented by the scholars are most pronounced in routine manual, blue collar and for workers who do not have a college education.

To avoid correlation biases, the authors verify for the impact of imports from China and Mexico, offshoring, other computer technology and total capital stock, finding distinct and weakly correlated effects.

Even when incorporating the increase in trade among commuting zones allowed by industrial robots' productivity gains, their effects on the employment share and wages are still consistently negative: one new robot reduces employment by 5,6 workers and wages by about 0,5% relative to a commuting zone with no exposure to robots.

The negative effects documented in this paper, however, rely on the relatively little number of industrial robots operating in the US. The IFR estimates that there are currently between 1.5

[15] https://en.wikipedia.org/wiki/Moravec%27s_paradox#cite_note-FOOTNOTEMoravec198815-1
[16] IFR,2014 cited by Acemoglu and Restrepo,2017

and 1.75 million industrial robots operating worldwide, a number destined to grow to 4 to 6 million by the beginning of 2025.[17]

Accordingly to these estimates, Foxconn Technology Group, a manufacturing giant which counts Apple, Microsoft and Sony among its clients, has announced already in 2011 its goal to reach one million of operating industrial robots in its factories. The firm's announcement came in response to the rising workers' salaries in China, where the firm employs 1.2 million people.[18]

Not only Foxconn, but the vast majority of the big business which offshored most of their production processes to low wage countries is responding to the rising wealth and thus, rising wages of Asian workers, by implementing huge investments in R&D to substitute them with industrial robots.

Since the most easily automatable tasks are the routine-based ones, production processes which require a low skill level are the first ones which will take advantage of the most recent technological developments and substitute robots for what has become a too expensive human labor.

The subsequent high exposure of Asian countries to automation is also documented by Jae-Hee Change and Phu Huynh (2016), who applied the research methodology developed by Frey and Osborne (2013).

The scholars analyze Cambodia, Indonesia, the Philippines, Thailand and Vietnam, which together account for almost 80 per cent of the entire ASEAN (Association of South East Asian Nations) workforce. (Jae-Hee Change&Phu Huynh,2016)

The results, shown in the following graphs, document the high automation risk for both the overall ASEAN-5 group and the single countries.

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[17] Boston Consulting Group,2015 cited by Acemoglu and Restrepo,2017

[18] Lee Chyen Yee, Clare Jim, August 1, 2011. Foxconn to rely more on robots; could use 1 million in 3 years, Reuters.

Figure 3. Distribution of employment at risk of automation

Source: Jae-Hee Change and Phu Huynh (2016)

The differences in automation exposure among the countries is caused by the different economies' industrial composition and educational level: if all of them produce textile and footwear production, it is also true that in Indonesia, the Philippines and Thailand garment manufacturing is more developed and has, thus, shifted up the value chain.

Taken in account the differences among countries, the risk of automation is nonetheless high in all of them, primarily due to their low educational attainment: "about 90 per cent of

Cambodia's workforce do not have a secondary degree […], in Viet Nam this figure is around 75 per cent [whereas] in Indonesia and Thailand, it is about 67 per cent."

The high risk of automation exhibited by these countries confirms how the replacement's wave allowed by the computers' developments implemented since the 1980s hit mostly high routine jobs such as production ones, for which developed nations' big businesses had found in low wage countries a way to preserve their international competitiveness.

2.2.3 Computers' most recent developments and new frontiers

After successfully accomplishing the substitution of routine tasks, computerization is now spreading to domains commonly defined as non-routine. Today, most of the efforts are aimed to turn non-routine tasks in explicitly defined problems.

To understand the speed at which computers are developing, the paper from Autor et al. (2003) can come to help. The scholars pointed, among the others, at the difficulties of replicating human perception in activities such as driving in the traffic. Only seven years later Google announced the full automation of several Toyota Priuses. (Frey&Osborne,2013)

This groundbreaking achievement was made possible by the combination of three highly interconnected technologies: the use of large and complex datasets containing detailed three-dimensional maps of road networks, i.e. big data, contained in the Google cloud storage, and the most recent advances in sensor technology, i.e. environmental control.

The use of big data is among the features which constitute the basis of Machine Learning. Machine Learning applies statistics and inductive reasoning to give best-guess answers when formal procedural rules are missing. The process undertaken by the machines before becoming operative is respectively composed by exposure, training and reinforcement.(Autor,2015b)

Autor (2015b) takes the challenge of object recognition of a chair as an example: "chairs come in innumerable varieties: some have four legs, some three, others have none; […] may or may not rotate, swivel, or telescope. […] This implies that the problem of object recognition […] likely requires reasoning about what an object is "for" and whether it is likely to serve that purpose".

Thus, what ultimately makes a chair is not a set of explicitly defined features, but its purposiveness. The reasoning-based approach which human brain goes through to recognize an object as a chair is extremely difficult to reproduce in machines.

Nevertheless, “many contemporary object recognition tools circumvent the reasoning problem by […] relying on very large databases of so-called “ground truth”. This approach does not require an explicit model of “chairness” […], instead, it relies on large training databases, substantial processing power, and of course sophisticated software.”

Thus, the machine is firstly exposed to data, then trained to recognize the object and reinforced with the addition of new data to overcome the errors observed.

As one intuitively guesses, the use of big data allows for the most different applications even in non-routine cognitive tasks, which have so far remained a human domain. Some scholars expect that computing power’s rise and training databases’ growth will eventually lead machine learning to approach or exceed human capabilities, whereas others are more cautious, believing how it will still be imprecise, particularly in the most exceptional cases. (Autor,2015b)

Cloud robotics, however, points to the direction of the former: the high speed at which data are transmitted nowadays have allowed the development of powerful centralized computational centers to which robots have constant access. This implies a sharp decline in robots’ creation, since a lower computational power and less memory storage are required; allowing at the same time for instantaneous upgrades to software installed in different machines.(Ford,2017) The data available through the data center will be constantly enlarged by the new knowledge acquired by the machines linked to it, boosting their learning speed.

Another path in which engineering and computer science are currently directing their efforts is environmental control.

As mentioned above, automated systems lack flexibility. For instance, modern automobile plants employ industrial robots to perform routine tasks such installing windshields on new vehicles. However, aftermarket windshield replacement is performed by technicians, due to the high flexibility and physical dexterity required. (Autor,2015a)

On the same token, online retailers have always employed a significant amount of workers to locate, collect, box, label and ship goods. Physical dexterity reveals itself as fundamental in such job, saving it from the wave of automation experienced by routine tasks.

This, however, applied until enterprises like Kiva Systems showed up: acquired in 2012 by Amazon, the firm produces hockey-disk-shaped robots ideated to move materials within a warehouse. Given their particular shape, these robots can pass under pallets or shelves to then lift and relocate them where they are needed. One year after the acquisition, Amazon already employed 1400 Kiva's robots. A Wall Street analyst estimated that these robots will allow the firm a 40% reduction in orders' management costs. (Ford,2017)

As Autor (2015a) writes: "the core of the Kiva system is a dispatch program that oversees the flow of all goods through the warehouse, coordinating the work of robots, which carry shelves, with the work of humans.[…] Robots handle only the routine task of moving shelves across a level surface; workers handle merchandise; and the dispatch software coordinates the activity."

Another brilliant application of environmental control is the self-driving Google car.

On this matter, researchers often highlight how the car does not drive on roads, but rather on maps. The automobile navigates through the road networks by comparing its real-time audio visual sensor data against detailed maps, reacting to obstacles, such as other cars or pedestrians, by braking and stopping. (see Autor,2015a)

Thus, Autor et al.(2003) were not wrong when they labeled driving as a non-routine activity and therefore difficult to automate. Researchers, indeed, did not reproduce the human processes that allow us to drive, but rather standardized an unpredictable environment such as roads.

Given such great achievements, it is unavoidable to see in the development of machine learning and environmental control, which will dispose of a continuously growing amount of data, the possibilities to overcome the major engineering bottlenecks encountered so far.

2.2.4 An even more skill-biased technical change

We earlier discussed how computer, by many scholars' opinions, has exacerbated what has been named a skill-biased technical change, which greatly favored the higher skilled workers and, to some extent, the lower skilled ones.

The modest growth experienced by the lowest tail is argued to be caused by the blooming of services, which has made possible for low-skilled workers in production jobs to avoid the job losses caused by automation of production processes.

However, the past and most recent technological developments show how services are among the new target of computer research.

The use of big data and the subsequent suggestions based on the previous purchases has made possible for e-commerce shops (e.g. Amazon, Ebay, Alibaba) to emulate the advices given by an assistant in a shop, using at the same time a way larger sample of products that the latter may ever have. Machine Learning earlier applications already suggest us which movie we may like on Netflix, which result we were looking for in the search engine, the more accurate translation for a certain foreign language's word.

Amazon, Ebay, Alibaba and the other e-commerce platforms are just at the beginning of their success: the e-commerce behemoths are implementing huge investments, with Alibaba alone announcing an expenditure of 15 billion dollars in R&D in push to become AI leader.[19]

Amazon, on the other hand, is not only substituting for human labor in the form of shop assistants, but has implemented plans to reduce the large number of human labor employed in the warehouses, deploying the Kiva System's robots discussed before.

Among the services targeted, food service is also at high risk of automation. Without taking in consideration the most elaborated food service ideas, which heavily rely on features such as creative cuisine and particular care by the waiters, fast food businesses could easily automate most of the tasks now performed by workers.

The highly routine tasks performed by fast food employees, together with the qualities beneath it (i.e. speed, rather than care or quality), represents a great occasion for robots such as the ones developed by Momentum Machines, which "can reportedly assemble and cook 360 burgers an hour."[20]
Considering that McDonald's alone employs 1,8 million people worldwide, the consequences of a complete automation in the fast food industry would have huge consequences on the employment. (Ford,2017)
Technology's diffusion has already caused a significant impact on jobs such as supermarkets' cashiers or bank tellers. Where six people were employed as cashiers, only one is now needed to take care of the same amount of automatic ones; on the other hand, the deployment of

[19] ANON., October 11, 2017. Alibaba launches $15 billion overseas R&D drive, Reuters.

[20] Chuy, Michael, James Manyika, and Mehdi Miremadi, July 2016. Where machines could replace humans—and where they can't (yet), McKinsey Quarterly.

ATMs led to a tiny increase of only 50,000 new bank tellers between 1995 and 2010, which equals to a drastic decline of the profession in the overall labor share. (Autor,2014)
On this regard, Frey and Osborne (2013) observe how the extent of computerization is likely to go well beyond that of offshoring. The latter, indeed, has always been restrained to jobs that do not need to be performed in a specific location nor face to face personal communication, whereas automation is destined to affect even these ones.

If the two substitutions discussed above have already occurred in a significant degree and are only expected to expand even more, other businesses are relatively recent: the market for personal and household service robots, for instance, is growing by about 20% annually. (Frey and Osborne,2013) The consistent improvements in sensor technology now allow to scan and map rooms while vacuuming, implementing a more sophisticated environmental control than the traditional "bump and turn" methods used by earlier generations. (Autor,2015b)

Technologies' new directions, however, are not pointed only to low-skill jobs' automation: a March 2011 story by John Markoff in the New York Times reports how Blackstone Discovery of Palo Alto, California (US), helped, with the use of a e-discovery software, to analyze 1.5 million documents for less than $100,000. Only in 1978 five television studios had examined six million documents at a cost of more than $2.2 million.

The cost advantages allowed by the e-discovery software, which are nothing but the most recent implementation of the Watson pattern recognition technology, are striking, and making hard to think of a future in which paralegals will experience anything but a drastic decline in their employment share and wage.

Also bookkeepers, accountants and auditing clerks, whose jobs require particular skills and training, perform, however, activities whose cost to automate is ridiculous, requiring mostly a software and a basic computer. Financial services and insurance provide another example: according to the MGI, 50% percent of the overall time of the workforce in finance and insurance is devoted to collecting and processing data, activities that have a technical potential for automation exceeding 60 percent.

Going upper in the skill ladder, technology decreases its labor-saving effect, while augmenting the complementary one: the hardest activities to automate, indeed, are "those that involve managing and developing people (9 percent automation potential), or that apply expertise to decision making, planning, or creative work (18 percent)."[21]

Nevertheless, high-skill professions do not require exclusively this kind of activities: 20 percent of a CEO's working time, according to MGI reports, could be automated by using current technologies.[22]

Two sectors that will most certainly experience a drastic change with the development of new technologies are healthcare and education.

Frey and Osborne (2013) write how "knowledge from 600,000 medical evidence reports, 1.5 million patient records and clinical trials, and two million pages of text from medical journals, are used for benchmarking and pattern recognition purposes."

Furthermore, Tom Gruber, co-creator of Siri, reported, during a Ted conference, how a diagnosing cancer software, relying on big data of slides observed by pathologists under the microscope to detect cancer cells, performed 92,5 percent of the answers correct.[23] If this result is still far from human accuracy (96,6%), there is little doubt that more sophisticated technology and larger amounts of data will allow to exceed human ability.

Besides the most sophisticated healthcare applications of new technologies which will significantly affect doctors and specialists, simple data collection, which accounts for two-thirds of nursing assistants' time[24], could be far easily automated. The gains obtained in these workers time could be then used to improve the hospitals' efficiency and service, causing, nonetheless, certain job losses.

On the other hand, in the education field, the rapid diffusion of MOOCs (Massive Open Online Courses) allows nowadays many people access to education directly from their PCs. If this will probably not substitute teachers worldwide, since "the essence of teaching is deep expertise and complex interactions with people", and, according to MGI, "[these skills] account for about one-half of the activities in the education sector"; it will unavoidably

[21] http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/where-machines-could-replace-humans-and-where-they-cant-yet

[22] http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/four-fundamentals-of-workplace-automation

[23] https://www.ted.com/talks/tom_gruber_how_ai_can_enhance_our_memory_work_and_social_lives?utm_campaign=social&utm_medium=referral&utm_source=facebook.com&utm_content=talk&utm_term=education

[24] http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/where-machines-could-replace-humans-and-where-they-cant-yet

change and reshape the way education is offered and grant a larger share of the world's population access to schooling.[25]

Thus, the incredible amount of current and potential applications of the new technologies seems to involve not only low-skill and highly routinized middle jobs in the immediate but gradually also a percentage of higher-skill ones.

The overall disruptive effect that they are expected to bring into society has been the effect of many studies, which tried to gauge the dimensions of their impact.

2.2.5 Which future for the employment?

One of the most quoted and discussed papers on the current automation is by Frey and Osborne (2013), who developed a new methodology to estimate the probability of computerization for 702 detailed occupations by asking experts about their technological potential in the near future. The scholars followed an occupation-based approach, avoiding explicitly taking in account macroeconomic compensations that technology may cause, focusing only on their substitution effects.

According to the results of their research, "47% of total US employment is in the high risk category, meaning that associated occupations are potentially automatable over a decade or two."[26]

Frey and Osborne believe that two waves of computerization will respectively take place, separated by a technological plateau, i.e. a phase in which research will have to cope with engineering bottlenecks regarding perception and manipulation, creative intelligence and social intelligence.

The automation probabilities for occupations requiring different skill levels are shown in the distribution below: the horizontal axis represents the skill level, whereas the vertical one shows the people employed for each occupation.

[25] Chuy, Michael, James Manyika, and Mehdi Miremadi, July 2016. Where machines could replace humans—and where they can't (yet), McKinsey Quarterly

[26] Frey and Osborne,2013 "The Future of Employment: How Susceptible are Jobs to Computerization?"

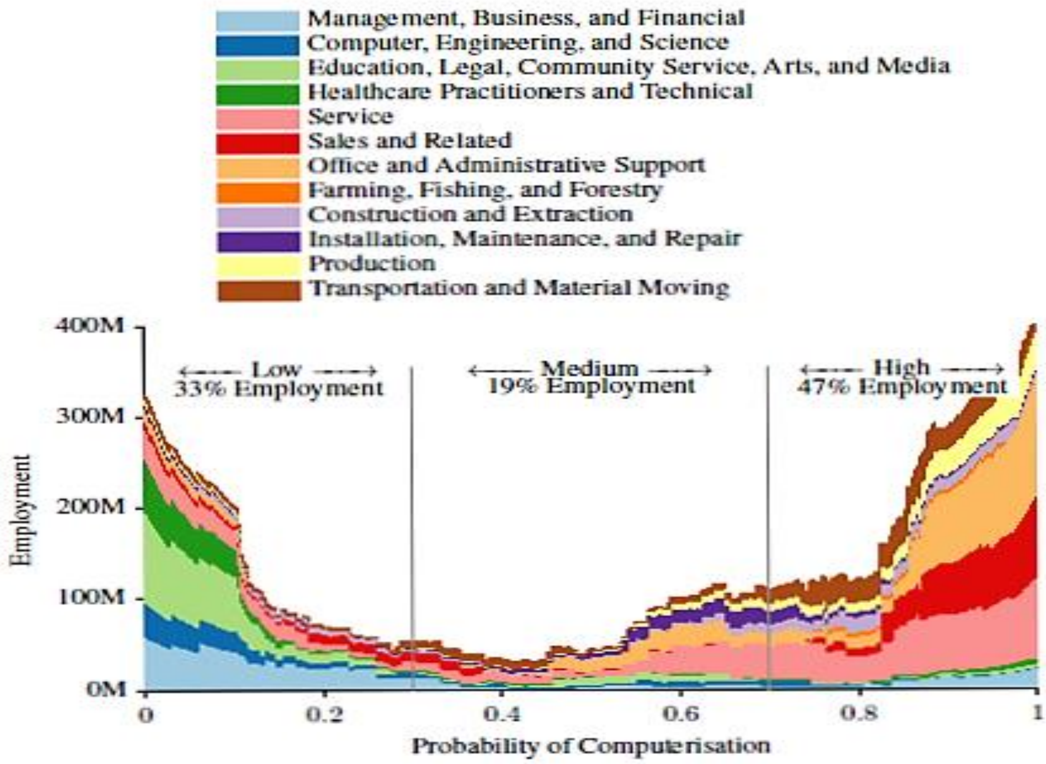


FIGURE III. The distribution of BLS 2010 occupational employment over the probability of computerisation, along with the share in low, medium and high probability categories. Note that the total area under all curves is equal to total US employment.

Source: Frey and Osborne,2013

The groundbreaking evidence found by the scholars led to a flourishing literature of academic papers applying their methodology to other nations (e.g. the ASEAN paper discussed above) in order to gauge their automation risk.

There are, however, some important limitations of the two economists' research that must be taken in account:

- Their approach is occupation-based, although many occupations require both routine and non-routine, manual and cognitive tasks.
- They explicitly avoid to take into account the capitalization effect, i.e. the job-creating effect of technological advances, together with the macroeconomic compensations brought by productivity growth
- They implicitly equal technical feasibility to automate and deployment of automation

Arntz et al. (2016) point out how an occupation-based approach "might lead to an overestimation of job automatibility", due to the significant share of tasks difficult to automate even in high risk occupations.

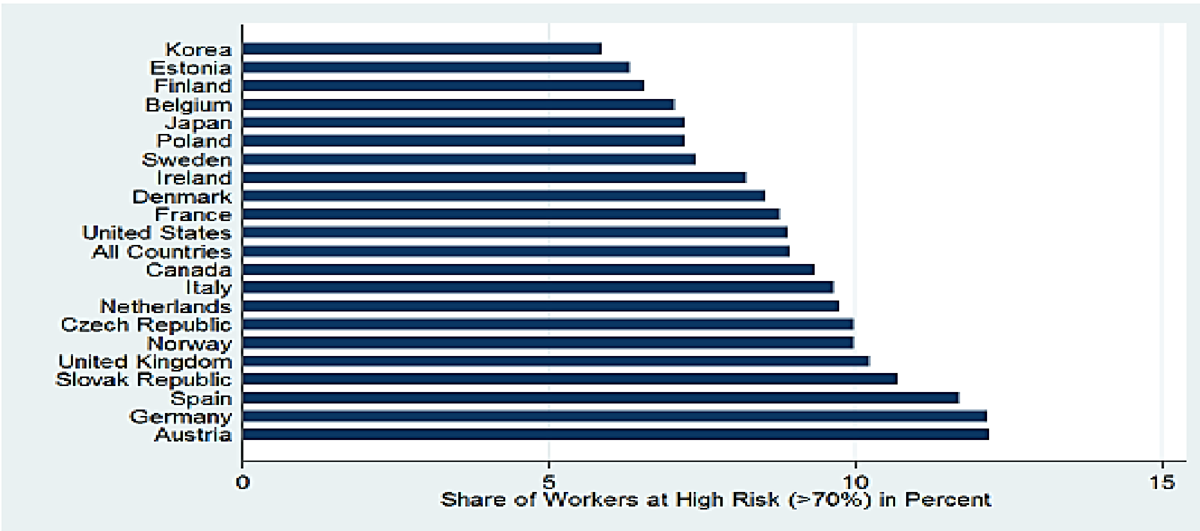
The difference between the occupation- and task-based approaches is crucial to correctly understand how new technologies will affect employment. For instance, if Frey and Osborne reported how bookkeeping, accounting and auditing clerks exhibit a potential for automation of 98%, Arntz et al. (2016) show how “only 24% of all employees in this occupation can perform their job with neither group work nor face-to-face interactions”.

The gap is striking even in the retail, where Frey and Osborne estimated an automation potential of 92%, whereas, as reported again by Arntz et al., “only 4% of retail salespersons perform their jobs with neither group work nor face-to-face interactions.”

On this regard, the MGI (McKinsey Global Institute) support the scholars’ approach: within manufacturing the technical potential for automation reaches 90% among the production tasks, whereas is below 30% regarding customer-service representatives. Overall, the results show a fewer than 5 percent of occupations susceptible of entire automation.[27]

Nonetheless, the Institute’s research shows how 45 percent of the activities workers perform, i.e. $2 trillion in annual wages, can be automated through the adaptation of current technologies, with an additional 13 percent if machines’ language level reached the median human performance.[28]

Figure 3. Share of Workers with High Automatibility by OECD Countries



Source: Authors' calculation based on the Survey of Adult Skills (PIAAC) (2012)

Source: Arntz et al.,2016

[27] http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/where-machines-could-replace-humans-and-where-they-cant-yet

[28] http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/four-fundamentals-of-workplace-automation

Following the more prudent and correct task-based approach on 21 OECD countries, Arntz et al. (2016) estimate the share of workers with high risk of automation (>70%) for each of them, finding a 9 percent of jobs completely automatable for the overall sample.

Commenting the results obtained, the scholars underline how it is however necessary to take into consideration at least three limits of their study:

1. The approach still matches technical feasibility with automation's deployment, an equation that in the light of the previous Industrial Revolutions does not appear realistic.
2. New technologies substitute for certain tasks while complementing for others. The possible automation of a workplace depends, thus, by the possibilities of changing the set of tasks performed, adjusting to automation within the occupation, rather than changing it. For instance, ATMs led bank tellers to focus on providing more services and investments' suggestions to the clients, rather than money. (Bessen,2015)
3. Finally, macroeconomic compensations which lead to an increase in labor demand need to be taken into account in the gauge of the total labor remained.

The first limit is well-documented by previous studies (David,1990; Greenwood,1999) which show how the effects of a new GPT were perceived only after a rather long time, due to the speed of diffusion and the speed of learning.

If, regarding the former, we have already provided consistent data showing how computer's price declined drastically since its invention and how robotics is also expecting to follow a fast price decrease (see Frey and Osborne,2013), speed of learning might be a more convincing argument.

The rapid pace at which technological change is occurring nowadays is undoubtedly unheard-of, leading many renowned scholars to talk about a Fourth Industrial Revolution after less than half a century since the Third Industrial Revolution outbreak. The human learning speed on how to take the best advantage from the new technologies, besides the superstar businesses' exception, is not keeping up, leading many firms to rely on previous investments on ICTs, which, by now, are already obsolete. Hence, this may lead to a rather slow diffusion of new technologies into economies.

Relatively to the second limit, Arntz et al. (2016) explains, as an example, how "tasks involving the monitoring of machines are likely to gain in importance."

Nevertheless, on this regard, Ford (2017) reports the case of Redbox, a movie rental society which relies on automatic machines for its products' distribution, employing only eight people in 2010 to monitor and restock 189 machines in the Chicago's area: if a machine ceases to work, a notification is immediately sent to a technician, who can login from his PC and solve the problem without moving to the site in which the machine is located.

A trend which underlies the new machines' development seems, indeed, the possibility of online maintenance, without operating directly on the machine. This obviously leads to a sharp cut to maintenance personnel, which in the past has always experienced a growth with the introduction of new machines.

Plus, as we have already discussed, bank tellers experienced a decline as a share of labor since the introduction of ATMs, demonstrating how adjusting still causes significant job losses.

Finally, regarding the macroeconomic effects of technology's introduction, the scholars distinguish three different mechanisms counterattacking the labor-saving impact of technological change.

First, the creation of new jobs by the ICT sector, which only in OECD countries amounted to 22% in 2013. (Arntz et al.,2016) However, the percentage of new jobs created does not represent an appropriate measure to gauge the possible gains in employment shares: in 1979 General Motors employed more than 800,000 workers, for a total revenue of 11 billion US dollars, when in 2012 Google made about 14 billion US dollars, employing no more than 58,000 workers.

The difference between the people employed by the two businesses is striking. Thus, the doubt lies on whether the high number of new jobs created by the Third Industrial Revolution firms will correspond to more people employed or a simple increase in jobs' variety.

On this regard, the McKinsey Global Institute reports how "one-third of new jobs created in the US in the past 25 years were […] in areas including IT development, hardware manufacturing, app creation, and IT systems management."[29] Besides hardware manufacturing, that nonetheless is being threatened by cases like the Foxconn's one, all the other jobs require high skilled work.

High-skilled workers, as pointed also by Acemoglu and Restrepo (2016), have a comparative advantage in performing new tasks, thanks to factors such as higher flexibility and learning

[29] https://www.mckinsey.com/global-themes/employment-and-growth/technology-jobs-and-the-future-of-work

speed. Thus, jobs like app creation, IT development or IT systems management will most likely benefit the high-skilled workers, with the ones replaced by automation left behind.

Secondly, new technologies typically increase a firm's productivity, leading, as a consequence, to lower costs and prices, which stimulate a higher product demand and hence a higher labor demand.

The compensation mechanism via decrease in prices described above is maybe the most important among the macroeconomic effects. However, it implies no demand constraints, the decision of firms to transfer the productivity gains in lower prices and thus, the lack of oligopolistic power in the relevant markets. (Pianta,2004)

A growing share of people unemployed, together with a larger share of the pie going to the wealthiest 1%, represent a quite good sample of demand constraints. If the main engine of the prosperity brought by the Second Industrial Revolution was the birth of mass consumption, wealth polarization will not substitute for it. As clearly observed by Ford (2017) a restricted club of billionaires is unlikely to supply mass production, hence, the concentration of wealth in the hands of a few people at the top does not represent a scenario sustainable by the present economy in the long run.

Thirdly, "to the extent that the new technologies complement workers, labor productivity increases. This may lead to either higher wages, or higher employment, or both, which in turn raises labour income." (Arntz et al.,2016) The increase in workers' wealth will then reflect on increasing demand for products and services, establishing a positive labor interaction in the economy. However, if only a rather low percentage of high skilled workers is complemented by the new technologies, the positive effects such productivity growth should deliver will not spread as wide as one may think.

Moreover, regarding the complementarity effect, Ford (2017) observes how the taxi driver profession, once requiring a vast knowledge of the city's topography, it has now been greatly deskilled by the GPS. Thus, although increasing the drivers' productivity, the new technology has inevitably lowered the skills required to perform such task, consequently enabling more unskilled workers to perform the same task. (See the Uber's case)

Given the new technologies' advances and the effects they may deliver on human labor, future seems rather dark for the employment as we move further on the second half of the chessboard. At present, we are not prepared to face the enormous impacts such a technological change would bring to our societies; hence, the implementation of economic policies is highly necessary.

3. Where do we go from here?

The risk that machines will substitute human labor to the point of causing what Keynes (1930) first defined "technological unemployment" has been the object of a flourishing literature among the scholars in the recent years, leading many researches on the topic to be published.

The views and positions on the topic vary from the supporters of the theory, such as Frey and Osborne (2013) or Brynjolfsson and McAfee (2011), to the more skeptical ones as Arntz et al.(2016), Autor (2014,2015a-b), Bessen (2015) and the McKinsey Global Institute.

Even the more skeptical agrees, however, on the fact that partial automation will occur. The intensity of partial automation, nonetheless, plays a crucial role: if the one experienced by the cashiers can be defined partial, since a person is needed yet, then the consequences on the employment will still be consistent.

Thus, the final result cannot depend on the sole economic forces, but necessitates institutions to intervene. A scenario in which low- and middle-skill—and thus, the vast majority of—laborers are unemployed, exacerbated by inequality reaching new peaks year after year, would put at high risk the social fabric, reinforcing discontent and causing deep fractures within societies.

3.1 To fight or to adapt?

Many measures have already been advanced to promptly react to the risk of a future characterized by a technological unemployment, although they have probably not been taken in sufficient consideration.

Taxing robots, for instance, has been proposed by personalities such as Bill Gates, who saw in this measure a way to delay the automation caused by the machines.[30] Wage rigidities such as minimum wage or a stricter regulation on workers' layoffs have been also claimed, together

[30] https://qz.com/911968/bill-gates-the-robot-that-takes-your-job-should-pay-taxes/

with a harsher capital taxation, to represent a practicable path to engage. However, these provisions, besides not allowing for a long term solution, present several important flaws.

To begin with, measures such as taxing robots would most likely be effective on firms which hugely rely on the environment in which they operate due to raw materials' provision or the existence of crucial clusters. Hence, firms which are not constrained by these factors would probably offshore in countries with fewer regulations.

Constraints on innovation have always faced a natural opponent: competition. However, if in the Industrial Revolution competition was limited to the European continent, the one we face today is worldwide. Thus, in the present days, taxing robots would most certainly reveal itself quite ineffective, given the several countries that would race to host the targeted businesses.

By the same reason, harsher capital taxation would be welcomed by similar countermeasures: many firms would move capital in countries with less regulations or taxes in an even easier way than plants. Therefore, these policies would be effective only if they were the result of a coordinated effort by many countries worldwide, which is, however, highly unlike.

On the other hand, the introduction of a minimum wage would sort no effect but a faster race for automation by the firms, given the higher cost labor would represent. This would possibly worsen workers' condition even more, leading to significant layoffs. To avoid such a situation, The Economist suggests to "top up wages with public money so that anyone who works has a reasonable income". [31] If this measure certainly has some qualities, nevertheless, it excludes a consistent share of population which is currently unemployed, granting aid only to the ones who perceive lower wages.

Brynjolfsson and McAfee in their book "Race against the machine" (2011) proceed on a rather more systematic "agenda for action" which does not consist in solutions aimed to slow down technological change, but in long term directives which would help economies to cope with it.

Among the many advices, the scholars point to the necessity of investments to improve the country's communication and infrastructure, an argument also supported by the MGI. As railways and roads have been essential for the diffusion of the technologies generated by the previous Industrial Revolutions, a complete and advanced communication network that ties the country together is essential to make a proper use of the present ones.

[31] https://www.economist.com/news/leaders/21594298-effect-todays-technology-tomorrows-jobs-will-be-immenseand-no-country-ready

Furthermore, an increase funding of the government R&D institutions, with "a renewed focus on intangible assets and business innovation" would allow avoiding a research's focus exclusively based on private investors' interests. (Brynjolfsson&McAfee,2011) Government R&D institutions would be free to direct their efforts to improve the living conditions of a larger share of society, and not mostly on processes' innovations to boost firms' productivity as it is now.

The groundbreaking innovations accomplished during the WWII remind us how the "national systems of innovation" have been the root of the wealth we have benefited for decades, leading to an overall enhancement of our societies. A renewed effort on R&D, no more coupled with military purposes but primarily focused on the enhancement of the population's living conditions, would most certainly allow for great long term benefits.

3.2 A universal basic income

The introduction of a minimum wage, both financed by the enterprises or the State, present the evident shortcomings underlined above. Nevertheless, the implementation of a universal basic income, although not representing a practicable solution in the long term, would be exempt by those flaws. Through a universal basic income financed by the State, firms would not rush to further automation nor would unemployed people be left behind.

This measure is firmly supported by Ford (2017)[32] as a way to react to the increasing automation many sectors will experience. The entrepreneur, however, does not lack to underline the possible negative effects this provision may provoke.

In particular, the incentive for people to work would be highly affected, with the risk of a significant share of the workforce quitting work and relying only on the income provided by the State. This possibility should, in Ford's opinion, be mitigated by allowing access to the universal basic income until not only people are employed, but perceive earnings characteristic of the middle class. Thus, the State's taps would close only in the moment a person earns an amount of money which consistently differs from the one the State would give him if he stopped working. According to the author, a correct way in the implementation of this measure would allow for a little percentage of people not having a job and living on a subsistence level, whereas the vast majority would work to improve its living conditions.

[32] But also supported by James Manyika, director of the MGI, and personalities such as Elon Musk, Tesla's founder, and Mark Zuckerberg. (see Moneycontrol.com in the references)

Furthermore, the distribution of a universal basic income would greatly help to overcome the previously discussed limits in the decreasing prices' mechanism. If this macroeconomic compensation's correct functioning may be undermined by the decreasing income perceived by a larger share of the population, the provision of a basic income would allow for a solution to the problem, finally stimulating mass consumption, and, as a consequence, mass production. (See again Ford,2017)

The implementation of this measure alone, however, would not lead to any solution to the possible unemployment experienced by an increasing share of the population, an issue that can be faced only with a particular attention on a fundamental aspect: human capital.

3.3. Never a trivial answer: education

We have earlier discussed how, according to many economists, a skill-biased technological change has occurred since the 1970s. The continuous enhancements of the Third Industrial Revolution's innovations have brought an unprecedented wave of disruption, which displaced many workers. Quite naturally, the people who managed to take the best advantage from the new technologies were the highest educated ones, due to their flexibility and faster learning speed. This led to a huge polarization in the labor market, with the high skilled workers experiencing most of the growth both in the employment's share and wages' level.

At present, new tasks are still being created in the most innovative firms, with no adequate supply of labor. This is an unavoidable consequence of the rapid pace with which innovation is proceeding: the costs decline at a high rate, fostering the new advances' adoption.

The obstacle remaining, thus, is the speed of learning by workers. The time required by workers to adjust to new technologies has not increased exponentially like the new technologies' advances, creating a consistent gap between the possibilities given by the innovations and their applications.

The several purposes a computer can serve, thanks to the wide range of software that has been developed, has led the Third Industrial Revolution to reach a pervasiveness' degree which no other Industrial Revolution has ever achieved. A trend that is impossible not to see, indeed, is that, since the very first machines led to the outbreak of the Industrial Revolution, technology has gained more and more importance, climbing over the factories' walls to enter every citizen's daily routine. This process inevitably leads a larger share of the population to cope with new technologies' mode of operation and thus, with the necessity of learning how to use them in the most productive way. Machines' knowledge and maintenance, a prerogative of the engineers in the previous Industrial Revolutions, has ultimately become, to some degree, necessary to every worker.

The higher embodiment of technology in the present societies must find a prompt response on the way education is provided. Guaranteeing a wider range of people to access higher education such as universities has been suggested by many scholars (Goldin and Katz,2008 above all) as the main way to mitigate the automation brought by the new technologies.

As we have seen above, the mass education provided by the US to its population at the dawn of the Twentieth Century has allowed the nation to reach a leadership position until the 1970s. With the outbreak of a new and faster Industrial Revolution, the answer must be even more rapid and determined.

Not only access to higher education must be granted to a larger share of population, education itself must radically change: basic use of ICTs should be taught in the school since the very beginning to then focus on more particular applications in high schools or universities. If machines' pervasiveness is destined to increase, it is presumably correct to assume that the value a worker will have in the future is deeply linked to his or her technology's knowledge. Thus, education should be restructured to combine traditional subjects and ICTs to allow taking the best advantage from the complementarity effects innovation brings. Plus, it should develop a new focus on features such as social (e.g. making unfamiliar combinations of familiar ideas) and creative (e.g. negotiation, persuasion and care) intelligence, which are the most complex human features to automate and thus, the ones in which automation encounters the major bottlenecks. (see Frey and Osborne,2013)

Reforming education and guaranteeing its access to a larger part of the population, instead of the policies listed above, would presumably allow for a long term solution to the workers' displacement caused by new technologies. The creation of a class of workers with more knowledge than the average on ICTs would most likely determine several effects which would compensate for the widespread automation:

- A renewed competitiveness of the country on the international stage which would be able to rely on a higher skilled workforce, becoming a reference point for the most innovative firms worldwide, and thus, attractive for their investments.
- An increasing percentage of the new jobs already created being standardized and reachable even by lower-skilled workers. If the standardization process described by Acemoglu and Restrepo (2016) is destined to occur and thus, lower the level of skills

required to perform the new tasks created by the technologies, a more skilled workforce on the ICTs will most certainly boost the process.

- An increasing number of totally new jobs and/or tasks created. If we assume the little jobs created by the Third Industrial Revolution so far is mainly caused, among the other factors, by the lack of a more widespread understanding on how to cope with new technologies, a deeper knowledge on the subject would allow for innovative applications and creative ideas, eventually stimulating employment.
- A reshaping of traditional jobs. An earlier approach on ICTs would allow for a ulterior development of the occupations created by the Second Industrial Revolution, which might evolve embodying new technologies, rather than being completely substituted by them.

A radical change in the educational system requires, however, a long time both to be implemented and to sort the desired effects. Thus, in the meanwhile, measures such as the universal basic income discussed above should be taken into consideration by policy makers to assist the growing share of unemployed.

Moreover, intervening on the formal education would obviously benefit only the future workforce, leaving the present one behind. Hence, together with the provision of a universal basic income, courses on ICTs' basic knowledge should be offered by the government to increase the probability for the low- and mid-skilled workers to find another occupation. More advanced courses should be implemented also for the workers already employed, financed by the firms in which they work, to allow for a constant retraining and upgrade on new technologies' possibilities and tasks.

Conclusions

Technology has historically led to disruptions in the short run, to then allow for widespread benefits in the long run: if mechanical looms and threshing machines displaced many workers, the latter found new jobs in the factories, which required a great amount of unskilled workers.

With the Second Industrial Revolution's advent, the world experienced the emergence of mass production, and thus, mass consumption. These two features strengthened each other, granting a steady and increasing wage to a large number of consumers. The new technologies, however, complemented higher skilled workers, whereas replacing the unskilled ones, breaking the complementarity formerly generated by the Industrial Revolution. The Third Industrial Revolution's outbreak, together with what many scholars named a Fourth Industrial Revolution, exacerbated the demand for skills, ultimately leading to a huge polarization of wages and employment. The new directions undertaken by research are aimed at reproducing more difficult human tasks, such as non-routine ones, which will have huge consequences in terms of unemployment and inequality. To promptly react to this scenario, measures such as a universal basic income or investments in education have been repeatedly argued by many economists.

Nevertheless, the sustainability of these measures relies on a fundamental assumption, i.e. that the complementarity effect is ultimately higher than the substitution one, and thus, that the exponential growth technology is experiencing is causing a prolonged displacement of workers mostly due to the relatively slow human learning pace. A subsequently increasing focus on education would help to mitigate the displacement, allowing workers to adapt quicker to the disruptions caused by the technological change. Furthermore, even within this hypothesis, if the exponential growth experienced by technology does not find any obstacle (e.g. consistent bottlenecks) on its way, it may outrun human learning to the point that, despite the adequate countermeasures adopted on education, human creativity will not supply enough jobs relatively to the ones machines automate.

On the other hand, if the substitution effect was greater than the complementarity one, then the economic policies listed above will not, since the very beginning, allow for a stable solution. If this was the case, in the long term we would assist to an almost complete disappearance of jobs, favoring capital owners and an increasingly thinner percentage of workers. Such a scenario would require huge incomes' redistribution together with a widespread welfare net to allow mass production to continue and avoid what would ultimately be the collapse of entire economies.

Hence, whether technological unemployment will finally occur or not, and the dimensions of the economic consequences it would bring if it does, largely depends on how fast and careful the institutions' response will be.

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